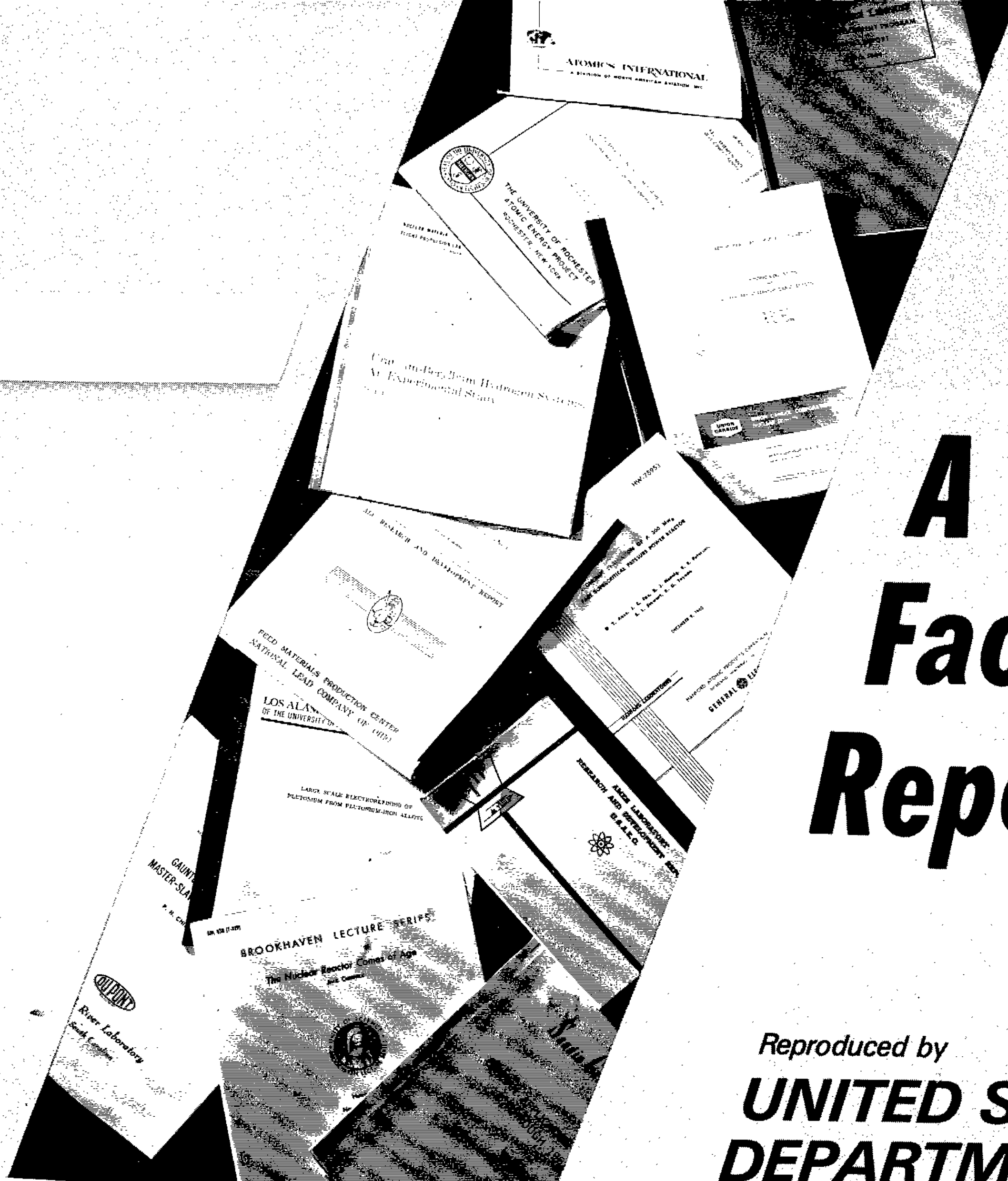

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SDI Performance and START Constraints: Modeling Phase-I Defense Engagements

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SDI Performance and START Constraints: Modeling Phase-I Defense Engagements

Chris Cunningham
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My interest has been the performance of near-term Strategic Defense Initiative (SDI) systems rather than the kinds of questions discussed at this Workshop (e.g., implications of U.S. force structure). It is clear, though, that the two issues are closely related. Arms control along with treaties that impact the force structure of the Soviet Union will greatly affect the performance of SDI systems. Similarly, the U.S. intention to pursue SDI will be a driver in arms control negotiations, as well it should be. Indeed, the implications of SDI for Strategic Arms Reduction Treaty (START)-constrained Soviet forces are the focus of my discussion. To put this in some context, I will begin with the premises underlying my results:

- The United States and the Soviet Union reach an arms control agreement limiting strategic forces below current levels.
- The United States decides to pursue defense deployments to limit damage to the U.S. and, eventually, to provide robust protection against ballistic missile attack.
- The Soviet Union responds by improving its forces within the numerical bounds of the treaty.

Let us say that the U.S. and the Soviet Union conclude a significant START treaty, reducing Soviet forces and that, subsequently, the U.S. decides to pursue a vigorous strategic defense deployment—deploying early generation defense assets. The Soviet Union then is either faced with losing its retaliatory capability or responding to the presence of the defense by modifying a reduced force. It is not clear how these two possibilities play off each other. One would think that smaller forces would make the defense task easier; however, smaller forces may be easier to modernize—this tradeoff is the basis for my presentation.

Table 1 shows how the Strategic Defense Initiative Organization (SDIO) sees its system evolving through the first few decades of the next century. Initially there would be a deployment of ground-based and space-based interceptors, which would enhance deterrence by allowing for the survival of U.S. retaliatory assets against a Soviet launch. Subsequently, there would be a growth toward a more effective defense, permitting damage limitation to a Soviet attack. However, the kinds of defense assets that would be needed to enhance deterrence against the rather large-inventory Soviet attacks that have been postulated might perform much better than this against START-constrained forces. Therefore, significant treaty-limited forces may be quite vulnerable to the presence of even a fairly modest offense, allowing the defense to do damage limitation.

In much of the previous work on strategic defense, the number of attacking warheads killed has been accepted as the basic figure-of-merit; however, Fig. 1 shows that analysts are now thinking in terms of the survival of the U.S. target base as the basic figure-of-merit, which is what I will discuss here.

In his presentation at this Workshop, Paul Chrzanowski showed a value construct with much of the target value concentrated in a fairly small proportion of the targets. It is this heavily weighted target-value spectrum that I will be using. We have seen this spectrum arise when we have considered the ability of the U.S. to mount a retaliatory response after an attack. It also appears in a value-related system developed for SDI analysis. I added the supposition that target hardness is also correlated to target value.

My analysis is based on the following:

- Minimize target value damaged.
- Assume a large target set: 10,000 targets.

Table 1. Current view SDI evolution. This is a branch and block approach; the nature of the defense is driven by the threat in the later phases.

	Year	Threat	Defense
Phase I	2000	Large numbers, conventional and responsive, significant penetration aids (penaids)	Kinetic energy weapons, space- and ground-based interceptors
Phase II	2008–2010	Transition, conventional, fast burn →	Kinetic energy plus first-generation beam weapons (mainly for decoy discrimination)
Phase III	2016–2020	Fully responsive, fast burn	Second-generation beam weapons

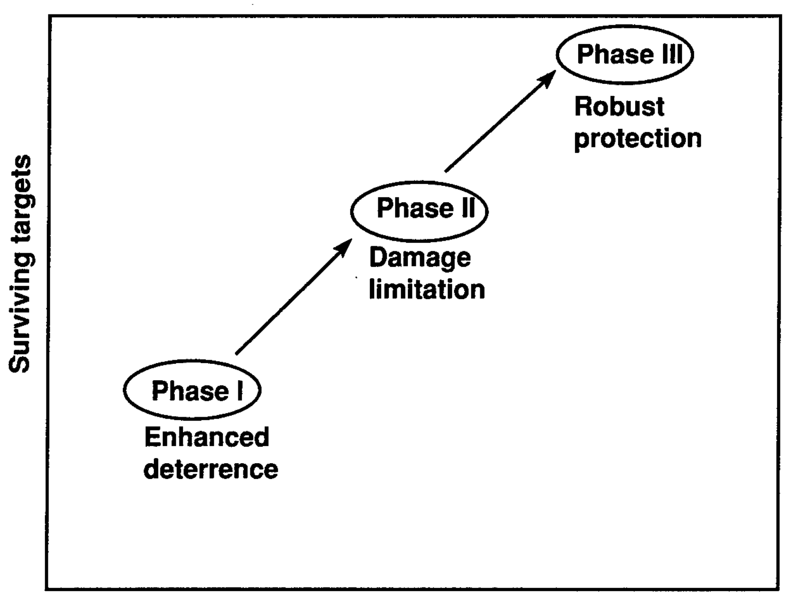

Figure 1. Evolution of the SDI mission. Survival of U.S. assets is the fundamental measure, not RV kills, and this contrasts with much of the previous work in this area.

- Use the value structure: $V(n) = n^{-\alpha}$.
  $\alpha = 1$
  –Arose recently in a study of the United States' ability to respond to a first-strike.
  –Put a premium on adaptive preferential defense.
- Correlate target hardness to value.
- Assume: $H(n) = 300\ \text{psi}/n^{1/2}$.
  –This spans the range 10 to 300 psi; unhardened industrial structures to shallow buried structures.

The above favors systems that have a good combination of yield and accuracy (e.g., SS-18) over systems that have much lower accuracy (e.g., the SS-24). It neglects an important fact, however, which is that a number of U.S. installations exist that are recognized as being of intrinsically very high value but are not particularly hard.

Because SDI is currently in a state of considerable flux, the following is only my own best guess for a Phase-I defense construct:

- Space-based interceptors (SBI)
  –Boost–post-boost vehicle (PBV) intercepts
  –Might be capable in midcourse
  –Cost: \$3–4M; 10-yr life-cycle cost (LCC) per active SBI
- Ground-based interceptor (GBI)
  –Exo-atmospheric intercept
  –Long range
  –Cost: \$1–2M; 10-yr LCC per active GBI
- Exo-endo interceptor (E^2I)
  –Long range terminal interceptor
  –Advanced sensors, high acceleration for high-endo commit
  –Might need radar adjunct
  –Cost: GBI < E^2I < SBI
- Phase-I buy
  –Assume \$20B for the interceptors (compare 50 MX/silos at \$21B; 20-yr LCC)

This guess includes the three components that have been discussed as possibilities for an early phase defense: a space-based interceptor tier (perhaps the singlet Brilliant Pebbles concept), and then two types of ground-based interceptors: a less expensive interceptor that is capable of exo-atmospheric commit only, or a more ambitious kind of an interceptor that can commit against targets as they reenter the atmosphere—using the atmosphere for decoy discrimination—and still preserve a fairly long flyout. This latter interceptor, which is large, would fly exo-atmospherically, would make a precommit while it and the threat were still exo-atmospheric, and then farther on would make a final commit as the target re-entered. This requires carrying a lot of acceleration capability to the target area and being able to operate on a very restrictive time line. Such a construct, the ability to use atmospheric discrimination, can have a big impact on the effectiveness of the defense. The number of interceptors needed for such a defense is not clear, several thousand might represent a buy that might be comparable to other kinds of defense assets. I will show that several thousand interceptors can perform quite well against a treaty-limited Soviet threat.

I took a construct (Table 2) that comes from May, Bing, and Steinbruner.* It has a suite of systems—SS-18s, SS-24s, and SS-25s, a number of different types of submarine-carried systems. I tried to determine what might represent a reasonable first-launch in a massive first-strike, withholding certain systems such as the SS-25 that would be useful to maintain as a deterrent on the ground. I show a non-START regime in which there is an arms control treaty freezing Soviet forces at basically their current level and then a much deeper reduction to about 45% of current force levels. These intercontinental ballistic missile (ICBM) forces are dominated by SS-18s; practically the whole SS-18 inventory is used in the first launch as well as a good share of the SS-24s, but very few of the SS-25s. Parameters for these conventional systems are as follows:

- Solid boosters (MX-like), 180-s boost.
- Liquid boosters (SS-18-like), 300-s boost.
- Conventional PBV (stressed MX), 30 s per RV.
- Basing
  –SS-18 at current sites.
  –SS-24 and SS-25 along the northern tier (SS-11).
  –Geographic concentration exploited for the START threat.

If there is a U.S. defense, the Soviets are going to respond to it. In my analyses, I investigated the following three responses:

- **Decoys only:** 20% of all payloads replaced with a mix of balloon decoys and reentry decoys.

*Michael May, George Bing, and John Steinbruner, *International Security*, 13(1), 90 (Summer 1988), as adapted by Paul Chrzanowski.

Table 2. **Order of battle in a massive attack.**

- About 60% of the total reentry vehicles (RVs) are used.
- START-level attack is about 50% of the current level.
- Numbers include a 10% launch failure rate.

Current Force Levels

	Launched		Withheld	
System	Boosters	RVs	Boosters	RVs
SS-18 Mod 5	277	2700	0	0
SS-24 silo	180	1800	0	0
SS-24 rail	0	0	200	2000
SS-25	90	90	500	500
Total ICBM	**547**	**4590**	**700**	**2500**
SS-N-8	129	129	143	143
SS-N-20	90	900	100	1000
SS-N-23	90	360	100	400
Total SLBM	**309**	**1389**	**343**	**1543**
Grand total	**856**	**5979**	**1043**	**4043**

START Force Levels

	Launched		Withheld	
System	Boosters	RVs	Boosters	RVs
SS-18 Mod 5	139	1390	0	0
SS-24 silo	49	490	0	0
SS-24 rail	0	0	70	700
SS-25	90	90	260	260
Total ICBM	**278**	**1970**	**330**	**960**
SS-N-8	70	70	78	78
SS-N-20	54	540	60	600
SS-N-23	43	173	48	192
Total SLBM	**167**	**783**	**186**	**870**
Grand total	**445**	**2753**	**516**	**1830**

- **Multiple PBVs:** SS-18s and SS-24s retrofitted with 4 PBVs carrying 2 RVs each. The cost is about $15M per missile, plus development programs.
- **SS-18 follow-on:** The booster burn time is reduced from 300 to 180 s. The cost is about $80M per missile, plus development programs. This is financed through a reduction in force size.

My assumptions about decoys are illustrated in Fig. 2. Many possible penaid suites have been described; using balloons and RVs encapsulated in balloons has long been a favorite of mine

because it almost completely denies the feasibility of passive discrimination in midcourse. Figure 2 shows a number of balloons in a cluster, two reentry decoys in balloons, and an RV encapsulated in a balloon. There are some technical uncertainties associated with the interaction of the encapsulation in the reentry decoys; these are a possible technical risk. Exo-atmospherically there may be a discriminant since not all of the balloons may be on appropriate trajectories. The following list identifies possible discriminants.

Midcourse

- Probably no simple passive discriminants.
- Balloon trajectories.
- Spin stabilization may be evident to Doppler radar.
- K = 1–2 (the fractional separation of the means of the discriminants).

Terminal

- Radar gives M/C_DA.
- Optical gives εA, shape.
- M may be determined.
- 20 kg/(0.1 m^2) gives 1 m/s^2 deceleration at ~100 km
- K = 2–3 (the fractional separation of the means of the discriminants).

Radar can see differences between the spin-stabilized RV in its encapsulation and the non-spinning decoys, but, nevertheless, this a difficult threat to discriminate exo-atmospherically. Endo-atmospherically (I assume ~10% mass reentry decoys), they will start having different dynamics at or below about 100 km, which is the regime in which these endo-atmospheric commits will be taking place, so some discrimination should be possible. Because of their mass only a few reentry decoys could be deployed, so certainly the focus of the battle will be endo-atmospheric.

Considering all of these factors together in a model (the threat, the target value scheme, and the defense), the defense and the attacker play a game in which the attacker tries to pick just the right targets for a system in terms of their values and hardnesses; the defense then tries to pick just the right strategy attacking the deployed RVs in three defense tiers, first using the space-based interceptors, then a commit of overlay interceptors, and finally a commit of endo-atmospheric interceptors. Figure 3 shows the results of this game in terms of the fraction of the value of the target base surviving—remember that the target value spectrum is fairly highly contrasted, most of the value resides in about the first 1000 targets in the value set. In Fig. 3, the value of the target surviving is plotted as a function of the force strength of the red ICBM and sea-launched ballistic missile (SLBM) assets: 100% represents a treaty-limited system at the current force level, and ~46% is the START-limited construct that I was considering. The lower curve, which permits almost no value surviving over most of the map, is the curve for no strategic defenses. However, if only a few thousand of these exo-atmospheric exo-endo interceptors that can make endo-intercepts are used, but no space-based interceptors are used, the curves shift upward radically, even with a fairly minimal force level. Here, the target value surviving is above 50%. Suddenly, because the offense is constrained to fairly small forces, we are not thinking of enhancing deterrence; we are thinking about denying the ability to significantly damage target value. In all of these calculations, I used a 20% replacement of payload with decoys, and that corresponds to the threat construct that I pictured in Fig. 2.

I also investigated sensitivity to decoy loading (see Fig. 4). In this case, the offense just cannot load on more decoys and do better, because it is treaty-limited and the payload used for decoys has to come at the expense of RVs. If the offence tries to make that trade, it finds that ~20% of the payload for decoys is about right. The offence would probably like to respond by deploying more missiles, and it probably has the money to do that, but it cannot because of the treaty limits. Thus, the existence of decoys does not negate the ground-based tier of the defense, even though the decoys are assumed to be difficult to discriminate. (In technical terms "poor" exo-discrimination means K = 1, and "fair" endo-discrimination means K = 2, with K the fractional separation of the means of the discriminants of the the two populations).

Figure 5 shows an added space-based interceptor tier and has four curves. The lower curve corresponds to 2000 SBIs alone. If they are assumed not to have a midcourse capability and if there are no other interceptors, the defense lacks the capability of doing a preferential defense. Preferential defense is necessary if target value is to survive, so this construct does not perform as well as others as far as saving target value. If

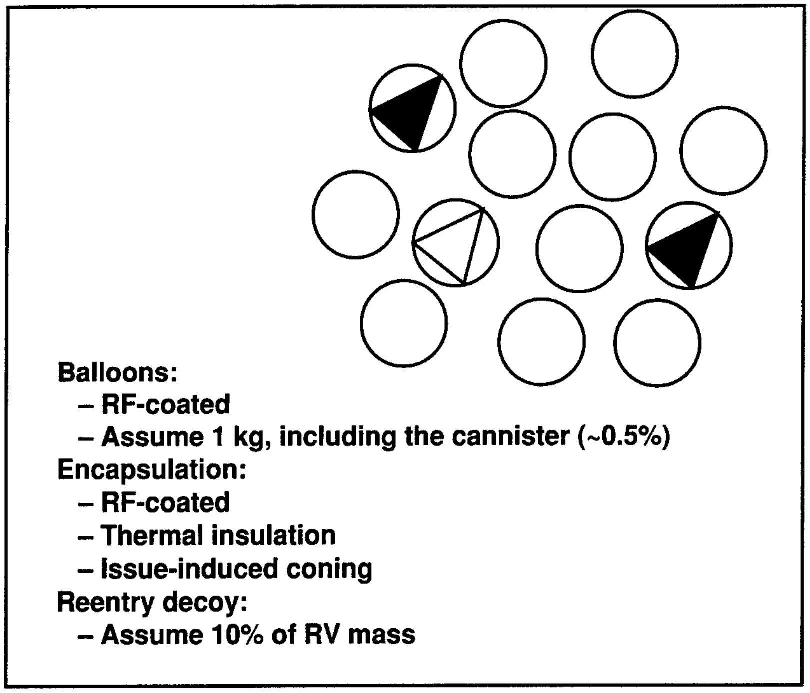

Figure 2. Penaid suite. One of many possible configurations.

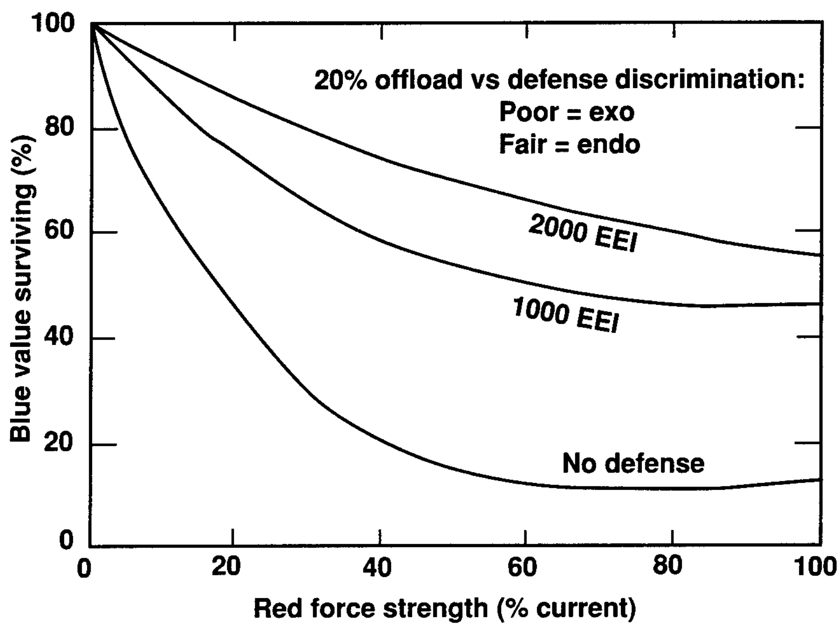

Figure 3. Limited forces against an adaptive defense.

the space-based interceptors are modified to come into play in the midcourse battle, the defense performs better, but in the midcourse battle the discrimination is not very good, so this is not an overwhelming advantage. The defense performs best when it uses space-based interceptors with a reasonable number of the endo-interceptors; they trade one for one—an endo-interceptor with a space-based interceptor—and maintain nearly equal performance. The specific result is largely driven by the assumptions that I have made about decoy discrimination. But the bottom line is that the space-based interceptor tier can be effective, even if preferential defense is necessary.

Some of the possibilities for redesign of the force in order to make it penetrate the space-based interceptor better are shown in Fig. 6. This figure illustrates a situation in which there are only the 2000 space-based interceptors, because this best shows the effects of modernization. The picture is, however, the same no matter what kind of defense construct, provided that it has extensive use of the space-based tier. The "conventional" curve means SS-18s with the normal 300-s burn and conventional PBVs. The "4 PBV" curve corresponds to multiple post-boost vehicles on the SS-18s and SS-24s. This option is relatively inexpensive, but it does not improve the offense's effectiveness very much. To penetrate through the SDI tier, the boost time for the SS-18s must be reduced—that is an expensive proposition but it might be financed by the savings in operating a smaller force. With a redesigned SS-18 booster, the START-constrained offense would be effective against a tier of 2000 SBIs.

Conclusions

My basic conclusions are:

- Under START and in the absence of defenses, the offense has sufficient weapons to attack 10,000 targets with strong value contrast.
- START constraints are severely limiting against an adaptive preferential defense, even with adaptive targeting.
- The adaptive preferential defense may contain a random-subtractive SBI tier.
- PBV redesign alone is insufficient to stress the SBI. Offload penalties to defeat endo-atmospheric interceptors appear significant.
- Despite increased flexibility to modernize, a small attacking force is vulnerable to a small defense.

If we do not have defenses, even under the START constraints, the Soviet Union has enough forces to severely degrade the U.S. target value. I used a construct that had a total of 10,000 targets. These results are not particularly sensitive to that total because of the steep contrast in target value. However, if there is an adaptive preferential defense, even though it may not have very many interceptors in it (only a few thousand), the START-constraint can extremely limit the attacker's ability to extract target value, even with the best possible offense allocation against the targets, knowing that defenses are present. This has implications for how the combination of a Phase-I defense and START will interact. Certainly the possibility of defenses will greatly complicate arms control negotiations. Adaptive defense is required, but this is not incompatible with a defense that has significant assets in a random-subtractive space-based tier; the later adaptive defenses can utilize what the random-subtractive tier does.

The threat, as far as redesigning its missile forces, has a relatively inexpensive option and that is to redesign the front end of the missile. This works quite well in the SS-24. The SS-18 is another matter; it needs a redesign of the missile itself in order to penetrate a space-based interceptor tier. In this START-constrained world, I could not identify an easy response of the defense to the presence of an endo-atmospheric interceptor. Decoys for the endo-interceptor have to be heavy, and the defense is constrained in the number of launchers that it can field. If it is going to put on heavy decoys, it has to take off RVs. In conclusion, if one decreases the size of the ICBM force, then one can defend against it with a small defense. The reduced cost for the offense to upgrade a smaller force does not seem to make up for this disadvantage.

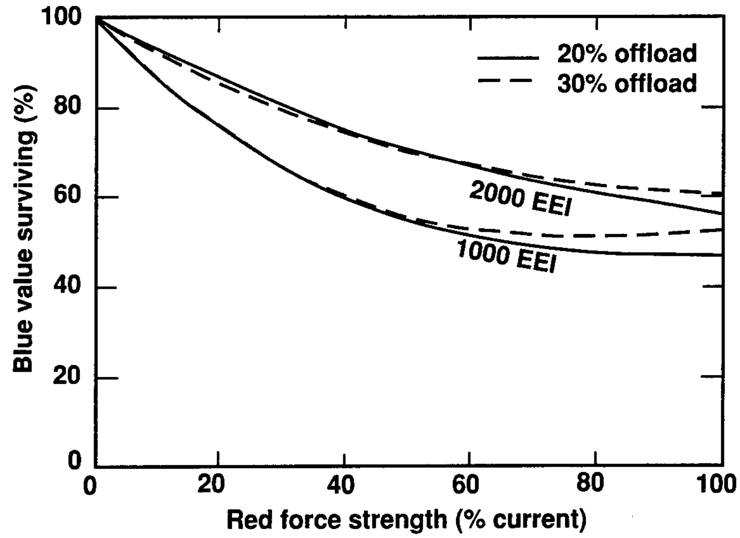

Figure 4. Increasing the offload does not help.

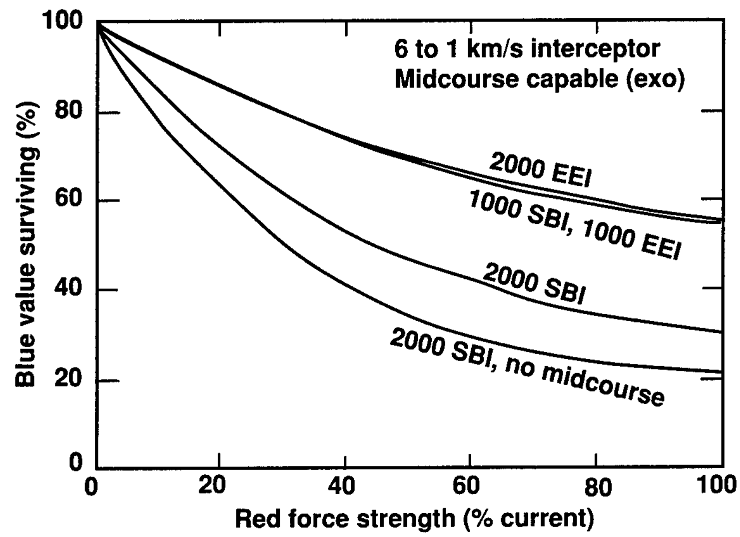

Figure 5. SBI tier is effective with an underlay.

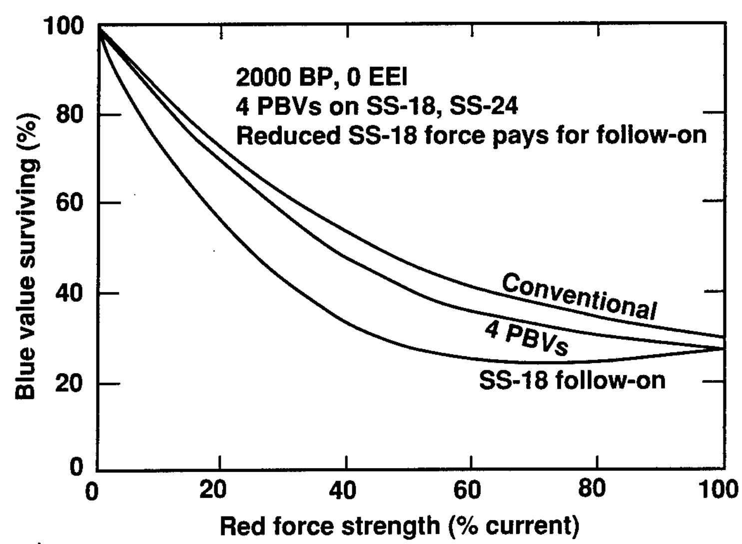

Figure 6. Booster, PBV redesign and SBI.

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